5-6-2021

Short-term outcomes of 59 dogs treated for ilial body fractures with locking or non-locking plates

Brian L. Petrovsky
Iowa State University, bpetro@iastate.edu

Taylor Knuth
Iowa State University, tayknuth@iastate.edu

Cristina Aponte-Colón
Iowa State University

William Hoefle
Iowa State University, whoefle@iastate.edu

Karl H. Kraus
Iowa State University, kkraus1@iastate.edu

See next page for additional authors

Short-term outcomes of 59 dogs treated for ilial body fractures with locking or non-locking plates

Abstract

Objective: To determine the influence of plating systems on the clinical outcomes in dogs treated for ilial fractures.

Design: Retrospective study.

Animals: Fifty-nine dogs (63 hemipelves).

Methods: Radiographs and medical records of dogs with ilial fractures presented to Iowa State University between 2003 and 2019 were reviewed. After fracture reduction, fractures were fixed with a locking plate system (LPS) or non-locking plate system (NLS). Perioperative, long-term complications, and follow-up data were recorded. The frequency of implant failure and pelvic collapse were compared using a logistic and linear regression analysis, respectively. Where the univariate test was statistically significant, a multivariate analysis across categories was performed to identify statistically different categories.

Results: LPS and NLS implants were used in 25/63 and 38/63 hemipelves, respectively. Median follow-up time was 8 weeks (3–624 weeks). Implant failure occurred in 18/63 (29%) of fracture repairs, consisting of 17 with NLS and 1 with LPS. Revision surgery was recommended in five cases of implant failure, all with NLS. The probability of implant failure was higher when fractures were fixed with NLS ($p = .0056$). All other variables evaluated did not seem to influence outcome measures.

Conclusion: The variable with the most influence on the outcomes of dogs treated for ilial fractures consisted of the fixation method (NLS vs. LPS). Fractures repaired with NLS were nearly 20 times more likely to fail than those repaired with LPS.

Clinical Relevance: Surgeons should consider repairing ilial body fractures in dogs with LPS to reduce the risk of short-term implant failure.

Disciplines

Small or Companion Animal Medicine

Comments

This is the published version of the following article: Petrovsky, Brian, Taylor Knuth, Cristina Aponte-Colón, William Hoefle, Karl Kraus, Jaron Naiman, Lingnan Yuan, Jonathan P. Mochel, and Eric Zellner. "Short-term outcomes of 59 dogs treated for ilial body fractures with locking or non-locking plates." *Veterinary Surgery* (2021). DOI: 10.1111/vsu.13656. Posted with permission.

Authors

Brian L. Petrovsky, Taylor Knuth, Cristina Aponte-Colón, William Hoefle, Karl H. Kraus, Jaron H. Naiman, Lingnan Yuan, Jonathan P. Mochel, and Eric Zellner

Received: 19 December 2020 | Revised: 13 April 2021 | Accepted: 26 April 2021

DOI: 10.1111/vsu.13656

ORIGINAL ARTICLE - CLINICAL

WILEY

Short-term outcomes of 59 dogs treated for ilial body fractures with locking or non-locking plates

Brian Petrovsky DVM[1] | **Taylor Knuth BS[1]** | **Cristina Aponte-Colón DVM[1]** | **William Hoefle DVM, MS, DACVS[1]** | **Karl Kraus DVM, MS, DACVS[1]** | **Jaron Naiman DVM, DACVS-SA[2]** | **Lingnan Yuan BS[3]** | **Jonathan P. Mochel DVM, MS, PhD, DECVPT, AAVPTF[3]** | **Eric Zellner DVM, DACVS-SA[1]**

[1]Department of Veterinary Clinical Sciences, College of Veterinary Medicine, Iowa State University, Ames, Iowa, USA

[2]Surgery Department, VCA Animal Specialty and Emergency Center, Los Angeles, California, USA

[3]Smart Pharmacology Biomedical Sciences, Iowa State University, Ames, Iowa, USA

Correspondence
Brian Petrovsky, Department of Veterinary Clinical Sciences, College of Veterinary Medicine, Iowa State University, Ames, IA, USA.
Email: bpetro@iastate.edu

Abstract

Objective: To determine the influence of plating systems on the clinical outcomes in dogs treated for ilial fractures.

Design: Retrospective study.

Animals: Fifty-nine dogs (63 hemipelves).

Methods: Radiographs and medical records of dogs with ilial fractures presented to Iowa State University between 2003 and 2019 were reviewed. After fracture reduction, fractures were fixed with a locking plate system (LPS) or non-locking plate system (NLS). Perioperative, long-term complications, and follow-up data were recorded. The frequency of implant failure and pelvic collapse were compared using a logistic and linear regression analysis, respectively. Where the univariate test was statistically significant, a multivariate analysis across categories was performed to identify statistically different categories.

Results: LPS and NLS implants were used in 25/63 and 38/63 hemipelves, respectively. Median follow-up time was 8 weeks (3–624 weeks). Implant failure occurred in 18/63 (29%) of fracture repairs, consisting of 17 with NLS and 1 with LPS. Revision surgery was recommended in five cases of implant failure, all with NLS. The probability of implant failure was higher when fractures

Results of this study were presented in part at the American College of Veterinary Surgery Virtual Surgery Summit Meeting 2020 and the Veterinary Orthopedic Society Virtual Meeting 2021.

were fixed with NLS ($p = .0056$). All other variables evaluated did not seem to influence outcome measures.

Conclusion: The variable with the most influence on the outcomes of dogs treated for ilial fractures consisted of the fixation method (NLS vs. LPS). Fractures repaired with NLS were nearly 20 times more likely to fail than those repaired with LPS.

Clinical Relevance: Surgeons should consider repairing ilial body fractures in dogs with LPS to reduce the risk of short-term implant failure.

1 | INTRODUCTION

Fractures of the ilial body account for 18%–46% of pelvic fracture cases in small animals.[1-3] Malalignment of the coxofemoral joint, compromise of the pelvic canal, injury to the lumbosacral nerve trunk, and incomplete transmission of weight-bearing forces may develop secondary to the inciting cause. Additional local trauma is common, including intra-abdominal, urinary, neurologic and soft tissue injury and hemorrhage.[4-9] A displaced and unstable fracture of the ilium is commonly treated by surgical fixation with a plate, or, in selected cases, with lag-screw fixation, intramedullary pins with figure-of-eight wire, external fixation, or a composite fixation technique.[10-12]

Outcomes following surgical management of ilial body fractures are reportedly excellent and generally result in a rapid return to function.[8,13-15] Complications associated with ilial fracture repair may be associated with inadequate fixation strength, resulting in nonunion, implant infection, and bone plate fracture.[3,16] If non-locking fixation failure develops, the mode of failure is usually screw loosening or pullout, rather than plate or screw breakage.[8] Screw loosening or pullout is associated with displacement of reduction, prolonged recovery, pelvic canal narrowing, and tensusmus.[17]

Various types of plates have been employed for the stabilization of ilial fractures, including dynamic compression plates (DCP), locking plates, cuttable plates, T plates,[18] miniplates, reconstruction plates, tibial plateau leveling osteotomy plates,[19] and double plates. Conventional plating techniques rely on friction between the plate and bone to provide stability, which may not be adequate in poor bone quality (i.e., cranial ilium) and can lead to implant and fracture motion.[2] Furthermore, the amount of compression between the plate and the bone necessary to generate friction has been shown to adversely affect the periosteal blood supply; and that has been linked to delayed healing, non-union, and increased susceptibility to bacterial surgical site infections after fracture repair.[20-23] Locking implant systems that do not rely on plate-to-bone friction to provide stability have been developed, and, consequently, eliminate the need for high shear load resistance at the screw-to-bone interface.[20,21,24,25] These systems provide more stable fracture repair, especially in poorer quality bone.[2] In addition, diminished plate-to-bone contact in these systems minimizes the negative impact on local vascularity during fracture healing.

To the authors' knowledge, the use of locking plates for repair of clinical canine ilial fractures has not yet been fully investigated and reported. Although two cadaveric studies did not show any difference biomechanically between locking and non-locking plates applied laterally to the ilium in acute failure testing,[2,26] other studies found a decrease in complications and screw loosening when locking plates were used for clinical ilial fractures in cats and dogs.[18,19] Additionally, two studies showed a decrease in complications and screw loosening when locking plate fixation was evaluated with triple pelvic osteotomy rather than non-locking plates.[25,27] The aim of this study was to determine the influence of plating systems on the clinical outcomes dogs treated for ilial fractures. The authors hypothesize that less implant failure will be noted with a locking system as compared to a non-locking plate system (NLS).

2 | MATERIALS AND METHODS

2.1 | Case selection

Medical records were reviewed for any dog that had surgically managed ilial fractures in which a bone plate and screw fixation were performed at the authors' institution between 2003 and 2019 and had follow-up at 6 weeks or later. Orthogonal radiographs of the pelvis pre- and post-operatively and at each scheduled recheck were required. Fracture repairs with incomplete medical records or radiographs that did not allow adequate evaluation were excluded.

2.2 | Medical records review

Information retrospectively reviewed were historical findings, signalment, clinical signs, diagnostic imaging, concurrent trauma, previous comorbidities, laboratory biochemical findings, procedural report, method of treatment, procedure time, hospitalization time, intraoperative and perioperative complications, and long-term (≥2 months) outcomes. The fracture severity and concomitant fractures were recorded from the preoperative radiographs. Pelvic fractures were classified according to the modified Association for Osteosynthesis/Association for the Study of Internal Fixation (AO/ASIF) pelvic fracture classification system as previously reported.[28] Follow-up was obtained through serial reevaluations including patient history, examination findings, and imaging when available. All patients were assessed on overall systemic health, ipsilateral limb neurologic issues, urinary/defecation systems, implant failure, reoperation, survival time, time of the last follow-up, and/or reason for death or euthanasia.

2.3 | Procedures

Each patient had an open reduction and internal fixation for an ilial fracture performed under general anesthesia. The patient was clipped and aseptically prepared in a routine fashion with a hanging leg technique and approached as previously described.[29] The ilial fracture was reduced, after which either a locking plate system (LPS) or NLS were applied according to AO principles.[17] Hemipelves were categorized based on the plate type and number utilized as NLS, LPS, multiple non-locking system (mNLS), and multiple locking-plate system (mLPS). NLS systems included: DCP, limited-contact dynamic compression plates (LC-DCP), and veterinary cuttable plates. For LPS, a single-plate String of Pearl (SOP; Orthomed, West Yorkshire, UK) was used. For mNLS, two or three non-locking plates were utilized. For mLPS, two or three locking plates of the SOP system were used. In some instances, an NLS and LPS system were used concomitantly and were classified as mLPS. Closure was routine and in accordance with surgeon preference.[29] Postoperative radiographs were performed on all patients prior to discharge.

2.4 | Postprocedural management

Upon anesthesia recovery, all patients were administered medications for pain management and antibiotics based on clinician preference prior to discharge.

2.5 | Follow-up

Physical examination and pelvic radiographs were recommended 6–8 weeks as necessitated after the procedure. Based on medical records, all patients were placed on exercise restrictions, pain medication, +/− antibiotics, +/− sedatives prior to discharge according to case specifications and surgeon preference.

2.6 | Outcome measure

Pelvic alignment, fracture apposition, apparatus, and activity at the fracture site were recorded from the immediate postoperative and follow-up radiographs by a single investigator (BP) on orthogonal radiographs and classified as anatomic, near anatomic, good, fair, or poor for all available radiographs.[16,30] The sacral index (SI) was recorded as previously described.[30] Changes in pelvic alignment were assessed by the change in SI from the immediate postoperative radiograph minus the last follow-up radiograph.

The following were used to describe the fixation implants: number of screw holes per implant, screws utilized per repair, screws per fracture fragment (cranial and caudal), cortices engaged by screws per fragment and in total (all fragments), and sacrum-to-ilium bone purchase (longest screw length as well as number of purchasing screws) in percent. Implant failure was defined as screw loosening, implant elevation or fracture, bone slicing, or fracture noted directly adjacent to the plate. Screw loosening was described by the change in screw purchase in the bone, as assessed on radiographs. The difference between immediate postoperative screw purchase and last follow-up screw purchase was calculated from review of the ventrodorsal radiographs. Radiographs were evaluated by a single investigator (BP) using imaging software (Synapse [PACS], Fujifilm Global, Tokyo, Japan).

The presence of perioperative complications, constipation, abnormal urination, neurologic deficits, and lameness was assessed based on the medical record, telephone follow-up (owner or primary veterinarian), and pelvic radiographs.

2.7 | Data analysis

Appropriate summary and descriptive statistics (proportions, means, medians, and ranges) were calculated for the outcomes and used to describe the distribution of the outcomes. Comparisons across LPS and NLS were performed in two steps. First, based on the limited sample size compared to the number of all covariate, a univariate logistic regression was performed to find predictive variables for implant failure. Then, a backward model selection based on the change in the Akaike Information Criterion (AIC) was performed to determine the best fit model.

The change in pelvic alignment, described by the change in SI (postoperative SI − follow-up SI), was compared across plate categories using linear regression through the same univariate to multivariate procedure. Where the univariate test was statistically significant, a multivariate analysis across categories was performed to determine which categories were statistically different. Perioperative, long-term complications, and follow-up data were recorded. Significance was set at $p < .05$ for all tests. Statistical analysis was performed in R 3.5 software (The R Foundation, https://www.r-project.org/).

3 | RESULTS

3.1 | Population

Out of 125 hemipelvis fractures initially identified, 57 were excluded due to inadequate case records or follow-up radiographs. Of these hemipelves that were excluded, 34 were NLS and 23 were LPS. The remaining 59 dogs (63 ilial body fractures) met the inclusion criteria. Enrolled patients had traumatic fractures sustained from being hit by a vehicle ($n = 59$), dog attack ($n = 2$), or of unknown origin ($n = 2$). Eighteen dogs were spayed female, 15 were intact female, 10 were male intact, and 1 was a neutered male. The dogs ranged in age from 2.75 months to 168 months at presentation with a median age of 26 months old. The most common breed noted in this population was Mixed ($n = 13$) followed by Labrador Retriever ($n = 8$), German Shepherd Dog ($n = 4$), Golden Retriever ($n = 4$), Cavalier King Charles Spaniel ($n = 4$), Dachshund ($n = 3$), and Jack Russel Terrier, Sheltie, Scottish Terrier, Shiba Inu, Cocker Spaniel, Beagle, and Border Collie (all $n = 2$); additionally, 14 different purebred dogs ($n = 1$). The median weight and BCS of the dogs were 14 kg (range, 1.8–41 kg) and 5/9 (range, 1–9), respectively. No statistical difference was noted between groups in respect to signalment, weight, BCS, or fracture cause. None of the patients in the study underwent an attempted repair of the pelvic fracture previous to referral.

Concomitant pelvic fractures were present in all animals (Table 1), the most common of which was 62-B1.X (i.e., unilateral involvement of weight-bearing structures with simple complete ilial body fracture) at 29% of the hemipelves. Ilial fractures involved unilateral, bilateral, or no involvement (ilial wing) of the weight-bearing elements in 54%, 43%, and 3% of the hemipelves, respectively. Three dogs had bilateral ilial body fractures that were repaired and were recorded as two hemipelves each. Overall, there was no statistical difference between groups in regard to fracture classification (severity or number of weight-bearing structures affected). Fracture classification was not associated with implant failure or postoperative pelvic collapse ($p = .38$). Twenty-three animals had concomitant sacroiliac luxation, of which, 20 were contralateral to the fractured ilium. Concurrent trauma was noted in 45 dogs (71%) with the most commonly noted concurrent trauma encountered being thoracic and abdominal trauma, seen in 29% and 20% of the population, respectively (Table 2).

TABLE 1 Count of fracture orientation and severity (Messmer)

Fracture orientation and severity	Count	Fracture orientation and severity	Count
62-B1.2	8	62-B2.1	1
62-B1.1	8	62-C3.312	1
62-B3.1	7	62-B3.3	1
63-B3.11	4	63-C1.311	1
63-B1.12	3	63-B1.21	1
63-B1.11	3	62-C2.3	1
61-B1.1	2	63-B1.23	1
63-B3.31	2	63-B3.12	1
63-B1.31	2	62-B1.12	1
62-B2.2	2	63-B3.32	1
63-B2.32	2	63-B2.11	1
62-B3.2	2	63-C1.3	1
62-C1.3	2	63-B2.12	1
63-B1.13	2	63-C2.311	1
63-B3.33	1	63-B2.22	1
62-C3.3	1	63-B2.23	1
62-B1.22	1		

3.2 | Implant selection and surgery

LPS and NLS implants were used in 25/63 (40%) and 38/63 (60%) of hemipelves, respectively. For NLS, DCP were utilized in 15 hemipelves, LC-DCP were used in eight hemipelves, veterinary cuttable plates were used in two hemipelves, and in 12 hemipelves the specific non-locking plate technology could not be determined. Additionally, one, two, or three implants were used in 43/63 (68%), 19/63 (30%), and 1/63 (2%) of hemipelves, respectively. Table 3 summarizes the median number of implant holes, screws used, screws cranial to the fracture site (screw purchase), and screws caudal to the fracture site (screw purchase). The median number of screws placed across the ilium into the sacrum was one per fracture hemipelvis (range, 0–4), with an average sacral purchase of 15.8% (range, 0%–90%). The sacrum was engaged in 25 hemipelves with NLS (average overall sacral purchase 16.3% [range 0%–50%]) and in 16 animals with LPS (average overall sacral purchase 15% [range 0%–90%]), but did not affect the rate of implant failure or pelvic collapse ($p = .46$) (Figure 1). No difference was found between groups in respect to implant selection (apart from NLS vs. LPS) and application. Lastly, there was no association between postoperative alignment or apposition and outcome ($p = .99$).

Other procedures were performed concurrently during the same anesthetic episode in 65% of patients. These included sacroiliac luxation repair ($n = 23$; 20 contralateral to fractured hemipelves), wound treatment/closure ($n = 4$), acetabular repair ($n = 2$), long bone fracture repair ($n = 8$), femoral head and neck excision ($n = 4$), abdominal exploratory ($n = 4$), coxofemoral luxation open reduction ($n = 2$), elbow luxation closed reduction ($n = 1$), spinal stabilization ($n = 1$), and zygomatic fracture repair ($n = 1$). Exploratory celiotomy was performed for uroabdomen, diaphragmatic hernia, penetrating abdominal wounds (no visceral trauma), and septic abdomen (jejunal perforation). All noted celiotomies were in one hemipelvis fracture each. Elective concurrent

TABLE 2 Concurrent trauma in the total population

Category of trauma	Count
Thoracic trauma (pneumothorax, pulmonary contusions, rib fractures, diaphragmatic hernia)	18
Contralateral sacro-iliac luxation	14
Abdominal trauma (hemoabdomen, splenic fracture, penetrating abdominal wounds, uroabdomen)	13
Wounds	9
Ipsilateral limb fractures/luxation	9
Contralateral limb fractures	4
Head trauma (skull fractures, traumatic brain injury)	4
Traumatic myocarditis	2
Ipsilateral sacro-iliac luxation	2
Spinal fracture/luxation	2
Contralateral wing fracture	2
Traumatic coagulopathy	1

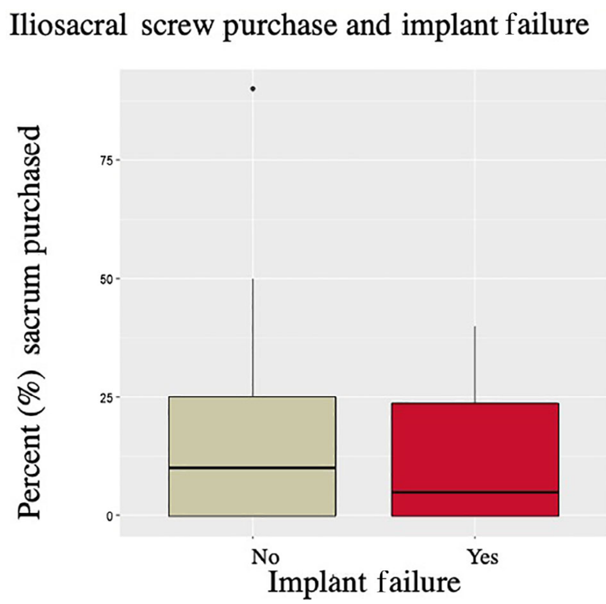

FIGURE 1 Influence of iliosacral screw purchase on implant failure. The sacrum was engaged in 25 repairs with non-locking plate system (NLS; average overall sacral purchase 16.3% [range 0%–50%]) and in 16 animals with locking plate system (LPS; average overall sacral purchase 15% [range 0%–90%]) without any influence on the rate of implant failure ($p = .46$)

TABLE 3 Statistical analysis of implant variables associated with cause implant failure

Implant system	L	NL	*p* value
Average implant length (holes total)	8.84	6.63	0.38
Average number of screws utilized (total)	8.16	6.53	0.38
Average number of screws in cranial segment	4.32	3.43	0.47
Average purchase cranially (number of cortices engaged)	8.32	6.86	0.47
Average of number of screws caudal segment	3.8	3	0.52
Average of purchase caudally (number of cortices engaged)	7.36	5.97	0.52

Abbreviations: L, locking; NL, non-locking.

desexing occurred in one male. Additionally, one hemipelvis was discharged 1 day postoperatively for urinary bladder repair to occur at the referral veterinary practice due to limited finances.

Overall, the median surgery time was 130 min (range 30–420 min), which included any concurrently performed procedure. Surgical complications were noted in two hemipelves. These complications were mild and composed of discrete hemorrhage that was controlled with electrocautery and ligatures; no blood products were given to either dog. Anesthetic complications were documented in 13 hemipelves, and was composed of hypotension ($n = 8$), hypothermia ($n = 8$), bradycardia ($n = 4$), arrhythmias ($n = 3$), hypercapnea ($n = 3$), regurgitation ($n = 1$), and preoperative anemia requiring blood transfusion ($n = 1$). Immediate postoperative SI index, alignment, and apposition were not different between groups ($p = .99$).

Hospitalization time prior to discharge was a median of 5 days (range 1–39 days). All animals survived to discharge. During hospitalization, 38% (24 hemipelves) of the animals exhibited signs of complications, most commonly being hyporexia ($n = 8$) followed by transient (resolving during hospitalization) urinary retention requiring urinary catheterization ($n = 6$), transient constipation ($n = 6$), sciatic neuropathy ($n = 4$), regurgitation ($n = 3$), wound management ($n = 3$), and seroma formation ($n = 1$).

3.3 | Follow-up

The median follow-up time was 8 weeks (range, 3–624 weeks). At the last follow-up, 96% of animals were alive, and none were euthanized/died from complications secondary to their pelvic fracture. Implant failure occurred in 18/63 hemipelves (29%), consisting of 17 NLS implants and 1 LPS (Figure 2).

The number of plates ($p = .039$) utilized for internal fixation, as well as the construct chosen (LPS vs. NLS), was significant on the univariate analysis ($p = .001$). However, the impact of plate number on outcome was no longer significant in the multivariate analysis ($p = .6658$) (Figure 3). In addition to the univariant analysis, the other recorded implant variables were not associated with either implant failure or pelvic collapse outcome measures (Table 3). The multivariate logistic regression revealed a significantly (19.5 times) higher probability of implant failure if NLS were used as the fixation method ($p = .0056$). Screw loosening was the most common implant failure encountered ($n = 15$) followed by plate elevation ($n = 9$) and bone slicing, plate bending and adjacent fracture (separately, $n = 1$). Screw loosening was more frequent for NLS than LPS. For NLS, screw loosening occurred in 15/38 (40%) hemipelves with a median percentage of screws loosening per construct being 50% (range 12%–67%), and which were evenly distributed between the cranial and caudal fragment (Table 4). Screw loosening was detected as early as 3–8 weeks in a majority (83%) of hemipelves. All NLS constructs with screw loosening in the cranial fragment had an initial screw purchase of the sacrum through the ilium to an average depth of 13.5% (range 0%–40%); when the constructs without sacral purchase were excluded ($n = 6$) the average sacral depth increased to 19.6%. The sacral screw loosened in nine NLS hemipelves. Plate elevation occurred in nine hemipelves with screw loosening. Plate elevation was not seen without screw loosening. For LPS, implant failure occurred in one hemipelvis and was characterized as bone slice that occurred in all screws in the

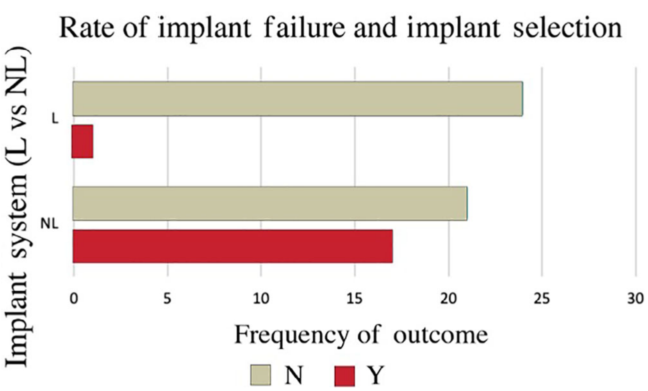

FIGURE 2 Influence of fixation method on implant failure. Implant failure occurred in 17/38 (45%) of non-locking plate system (NLS) implants and 1/25 (4%) locking plate system (LPS) ($p = .0056$)

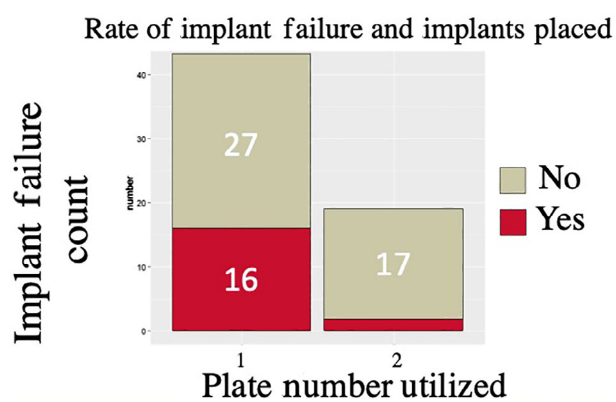

FIGURE 3 Influence of the number of implants used to repair the fractures and implant failure. One, two, or three implants were used in 43/63 (68%), 19/63 (30%), and 1/63 (2%) of the repairs, respectively, without apparent influence on outcome ($p = .6658$)

TABLE 4 Basic characteristics of 18 implant failure hemipelves

IF case	Implant genre	1vs2 plates	Locking versus non-locking	Holes total	Screws total	Screw purchase cranially	Screw purchase caudally	Number of screws in sacrum	% Sacrum purchased	Outcome	Number of screws moved/total	Additional surgery
1	2.7 SOP	1	L	6	5	6	2	1	5	BS	2/5	N
2	2.7 DCP	1	NL	6	5	6	4	1	10	SL, PE	2/5	Y—Explant
3	2.7 LC-DCP	1	NL	6	6	6	6	2	5	SL, PE	4/6	N (recommended)
4	2.7 DCP	1	NL	7	7	8	6	1	5	SL, PE	4/7	Y
5	2.7 DCP	2	NL	10	10	8	12	1	40	SL, PE	5/10	N
6	3.5 LC-DCP	1	NL	6	6	6	6	0	0	SL, PE	3/6	N
7	2.7 DCP	1	NL	5	5	6	4	2	5	SL, PE	4/5	N
8	2.7 DCP	1	NL	6	6	6	6	2	15	SL	2/6	N
9	2.0 DCP	1	NL	6	6	6	6	0	0	SL	1/6	N
10	3.5 LC-DCP	1	NL	7	7	8	6	0	0	SL	1/7	N
11	3.5 LC-DCP	1	NL	8	8	8	8	1	25	SL	1/8	N
12	3.5 Broad DCP + 3.5 reconstruction plate	2	NL	11	11	14	8	2	25	SL	7/11	N
13	3.5 Broad DCP	1	NL	7	7	8	6	1	20	NF		Y
14	3.5 DCP	1	NL	7	7	8	6	0	0	SL, PE	2/7	N
15	3.5 DCP	1	NL	7	7	8	6	2	40	SL, PE, DSSI	4/7	Y—Explant
16	3.5 LC-DCP	1	NL	6	6	6	6	1	40	SL, PE	3/6	N
17	3.5 LC-DCP	1	NL	5	5	4	5	0	0	SL	2/5	N
18	3.5 DCP	1	NL	8	8	8	8	0	0	PB	N	

Abbreviations: BS, bone slice; DCP, dynamic compression plate; DSSI, deep surgical site infection; IF, implant failure; L, locking; LC-DCP, limited-contact dynamic compression plate; NL, non-locking; PB, plate bending; PE, plate elevation; SL, screw loosening; SOP, string of pearls.

caudal fracture fragment. Evaluation of the immediate postoperative radiographs revealed the most caudal screw in the cranial fracture segment was placed into the fracture site—a result from improper surgical technique or preoperative planning. The fracture had a delayed union and malunion with pelvic collapse noted (SI change −0.50), but the patient was asymptomatic for the pelvic collapse and reportedly normal. At the last follow-up, 9 weeks postoperatively, this animal was bearing weight well and had undergone formal physical rehabilitation. No implant failure was observed for any animal with mLPS. No association was found between implant failure and injury to the contralateral weight-bearing axis or concurrent trauma/fractures. Overall, revision surgery was recommended by the overseeing clinician based on medical record review in five of the dogs that had implant failure, all of which were NLS. Delayed and malunions were noted in 8 and 10 of implant failure hemipelves, respectively, and were only noted in hemipelves with implant failure. In the single case where revision surgery was recommended but not pursued by the client, there was a discrepancy between the owner's perceived function and the clinical impression at the 6-week postoperative recheck. The patient exhibited signs of having pain on hip range of motion. Radiographically, this case had four loose screws, plate elevation, loss of fracture alignment/apposition, and no boney callus formation. In NLS implant failure hemipelves that did not have a recommendation for reoperation ($n = 12$), assessments were present for seven, of which all had adequate clinical function at last follow-up as noted on medical records. Two of these dogs had noted pain on hip range of motion ipsilateral to the site of the fracture. No objective gait analysis, pain scoring system, or goniometry was performed.

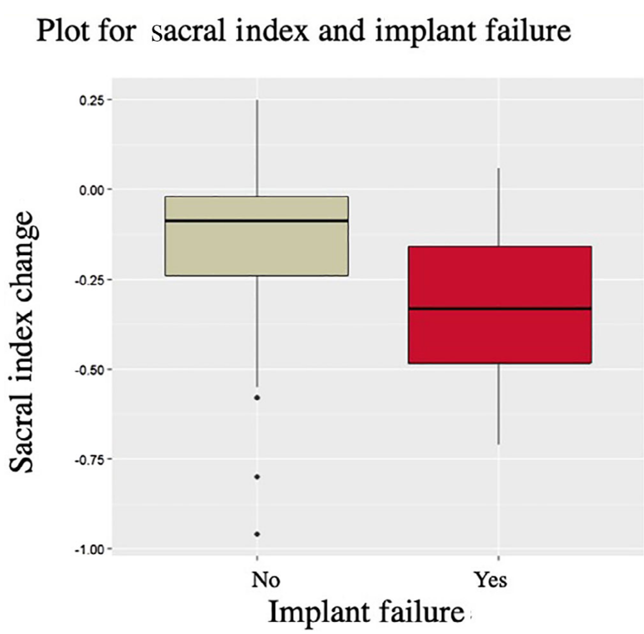

FIGURE 4 Association between sacral index and implant failure ($p = .018$)

The mean change in SI for NLS was −0.2 (range, −0.7 to 0.3), for LPS was −0.07 (range, 0.96 to 0.11). The change in SI was not different across categories and no variable affected this outcome. The change in SI was noted as a significant variant for implant failure ($p = .018$) as represented in Figure 4.

At last follow-up, none of the animals showed signs of long-term constipation, abnormal micturition, or problems on parturition associated with pelvic collapse based on review of the medical records, radiographic evaluation, or owner report. Persistent sciatic dysfunction was noted in three hemipelves.

4 | DISCUSSION

In the population evaluated here, repairing canine ilial body fractures with locking plate reduced short-term implant failure compared to fixation with non-locking plates. The authors therefore recommend locking over non-locking fixation of ilial body fractures in dogs to reduce the risk of implant failure. None of the other factors evaluated in this study influenced implant failure or the change in SI as a measurement for postoperative pelvic collapse.

Locking plate constructs in this study were associated with a nearly 20-fold decreased risk of implant failure compared to non-locking plates. The reasons can likely be attributed to biomechanic and biologic contributions. Non-locking plating relies on compressing the plate to the cortical surface, generating frictional forces. Once the frictional force between the plate and the bone is overcome, the cis-cortex for that screw experiences high stresses, which can result in bone resorption, toggling, and screw loosening.[24] Locking plates result in a continuous "angle stable" plate-screw interface, which acts to prohibit the toggle effect and does not require bone contact prohibiting vascular compromise.[24] In the recent literature there are two biomechanical studies on canine ilial fracture models comparing the Locking Compression Plate[2] versus DCP, or SOP[2] versus DCP constructs in an acute failure model. In both publications, there were no differences found in comparison.[2,26] Contradictory results from feline ilial fracture gap models determined that single-locking plates produced superior constructs compared with single-non-locking constructs.[31] The present study was not able to evaluate the interaction between the LPS-provided biologic and biomechanic factors. As translated from the findings of this study, locking plates resulted in no implant failure when AO principles were followed.

The most common complication associated with ilial fracture repair is implant failure, which occurs in up to 62% of patients.[16] In our cohort, implant failure occurred in 29% of patients, consisting of 17 NLS implants and 1 LPS. The majority of the failures were due to screw pull-out (83%). The authors note that the toggle effect of the screws is mitigated by LPS as compared to NLS; thus, cycling and screw loosening occur more with the NLS systems. The finding of decreased screw loosening with LPS as compared to NLS was found in a recent evaluation of cat ilial fracture repairs.[30] Five of the dogs in this cohort with implant failure were recommended to have revision surgery, indicating that nearly a third of the patients with implant failure were significant enough to affect patient outcome in the short term. Not all instances of implant failure required revision surgery, such as minor screw loosening after the fracture healed. Of note, due to the retrospective nature of this study, the recommendation for re-operation may be under-reported and not all records reported clear reasons for recommending re-operation. The clinical relevance of our findings is unclear, but the authors theorize that worse short-term clinical outcomes were suspected to occur in the re-operation group.

The number of plates utilized during surgery did not affect the outcome measures in this cohort. This should be interpreted with caution. Schmierer et al. determined that double LPS have improved stiffness and resistance to failure compared to single NLS, double NLS, and single LPS in a feline ilial body fracture gap model.[31] The locking plates utilized in this cohort were the SOP (Orthomed) system, which is versatile to accommodate complex contouring and reduce weakening of the plate during bending.[24] Nesting SOP plates are clinically valuable, as seen in 32% of hemipelves in this study. In a 2015 study comparing double SOP plating versus single DCP constructs in a bone model, the double SOP constructs had greater bending stiffness, bending strength, bending structural stiffness, and torsional stiffness.[20] One reason the authors suspect the number of plates may not have shown a clinical advantage is that the bone stock of our cohort was able to accommodate a relatively large amount of screws (see Table 3), as opposed to a cat or a small dog where ilial cranio-caudal length may be limited, making nesting more valuable.

Pelvic canal narrowing is commonly noted in previous clinical studies and seemingly has minimal clinical consequences in dogs.[3,16,32] Our findings concur; transient constipation was seen in six dogs, and was not noted long-term in any. The authors consider the cause is likely secondary to soft tissue swelling and pain rather than pelvic collapse. The change in SI in this cohort was minimal (mean: NLS −0.2; mean: LPS −0.07), and not correlated with any variable evaluated in this study.

This study has several limitations. First, the data was collected were retrospective in nature with limited case numbers due to multiple exclusion criteria. Of note, a small majority of the 57 hemipelves that were excluded were NLS ($n = 34$); if records were present on all cases this may alter the results presented. Additionally, no prospective or objective gait analysis was performed in each case to further assess case outcome. As with any retrospective study, the application of treatment was not randomized, and plate selection was at the surgeons' discretion. Surgeons may have opted to use an LPS for more severe fractures, creating a selection bias. However, given that the Messmer scale was not different between groups, this bias may not be present.[28] Additionally, all LPS were of a single system and may not be directly comparable to other locking plate systems. Further work would be necessary to directly compare different locking plates with their efficacy on ilial body fractures. Follow-up ranged from 3 to 624 weeks (median 8 weeks), which may have impacted the detection of pelvic narrowing or subclinical implant failure. However, in this short-term evaluation, screw loosening was detected as early as 3–8 weeks in a majority (83%) of the repairs affected by screw loosening, such that minimal screw loosening was missed. This is similar to a previous study on cats.[30] Furthermore, long-term radiographic and clinical assessments would be required to make definitive recommendations regarding implant superiority. All measurements were taken by a single observer potentially leading to bias; however, this would be systematic across all fractures. The radiograph reader could not be blinded to fixation type because the implants were clearly visible. This could bias the assessment of fracture repair, but since the SI was objectively measured, it is not likely to be affected by reader bias. The radiographs evaluated in this study were not calibrated, as a percentage was judged to be a better estimate across different sized patients. Both ACVS residents and diplomat fracture repairs were included and not differentiated in this study. Further analysis regarding experience, learning curve, and its associations on the groups here would be of interest.

In conclusion, the variable with the most influence on the short-term outcomes of dogs treated for ilial fractures consisted of the fixation method (NLS vs. LPS). It is unknown whether this was primarily the result of the biomechanics or due to better periosteal perfusion of the LPS (as compared to NLS). Fracture repairs in which NLS were utilized were 20 times more likely to develop implant failure than those with LPS. Surgeons should consider repairing ilial body fractures in dogs with LPS to reduce the risk of short-term implant failure.

ACKNOWLEDGMENTS

The author(s) received no specific funding for this work. At the time of the study, Dr. Karl Kraus was a paid consultant for Orthomed, West Yorkshire, UK, the distributor of the SOP implant that was used.

CONFLICT OF INTEREST

The authors declare no conflicts of interest related to this report.

AUTHOR CONTRIBUTIONS

Brian Petrovsky: study design, data collection and interpretation, case enrollment, manuscript preparation and submission. Taylor Knuth: data collection and interpretation, manuscript revision and acceptance of final version of submitted manuscript. Cristina Aponte-Colón: data collection and interpretation, manuscript revision and acceptance of final version of submitted manuscript. William Hoefle: manuscript revision and acceptance of final version of submitted manuscript. Karl Kraus: manuscript revision and acceptance of final version of submitted manuscript. Jaron Naiman: study design, manuscript revision and acceptance of final version of submitted manuscript. Lingnan Yuan: study design, statistical analysis and interpretation, manuscript revision. Jonathan P. Mochel: study design, statistical analysis and interpretation, manuscript revision and acceptance of final version of submitted manuscript. Eric Zellner: study design, data collection and interpretation, case enrollment, and manuscript revision and acceptance of final version of submitted manuscript.

ORCID

Brian Petrovsky https://orcid.org/0000-0001-9526-9624
Eric Zellner https://orcid.org/0000-0001-5959-0138

REFERENCES

1. Ljunggren G. Fractures in the dog: a study of breed, sex, and age distribution. *Clinical Orthopaedics and Related Research (1976–2007)*. 1971;81:158-164.
2. Bruce C, Gibson T, Runciman R. A comparison of conventional compression plates and locking compression plates using cantilever bending in an ilial fracture model. *Vet Comp Orthop Traumatol*. 2014;27(6):430-435.
3. Breshears L, Fitch R, Wallace LJ, Wells C, Swiderski J. The radiographic evaluation of repaired canine ilial fractures (69 cases). *Vet Comp Orthop Traumatol*. 2004;17(2):64-72.
4. Lanz OI. Lumbosacral and pelvic injuries. *Vet Clin North Am Small Anim Pract*. 2002;32(4):949-962.
5. Gant P, Asztalos I, Kulendra E, Lee K, Humm K. Retrospective evaluation of factors influencing transfusion requirements and outcome in cats with pelvic injury (2009–2014): 122 cases. *J Vet Emerg Crit Care*. 2019;29(4):407-412. https://doi.org/10.1111/vec.12852.
6. Selcer B. Urinary tract trauma associated with pelvic trauma. *J Am Anim Hosp Assoc*. 1982;18:785-793.
7. Gilmore D. Sciatic nerve injury in twenty-nine dogs. *J Am Anim Hosp Assoc*. 1984;20(3):403–407.
8. Tomlinson JL. Fractures of the pelvis. In: Slatter DS, ed. *Textbook of Small Animal Surgery*. Philadelphia, PA: Elsevier Health Sciences; 2003:1989-2001.
9. Hoffberg JE, Koenigshof AM, Guiot LP. Retrospective evaluation of concurrent intra-abdominal injuries in dogs with traumatic pelvic fractures: 83 cases (2008–2013). *J Vet Emerg Crit Care*. 2016;26(2):288-294.
10. Burton NJ. Composite fixation of comminuted ilial wing fractures in cats: three cases. *J Feline Med Surg*. 2011;13(5):376-382.
11. Vangundy T, Hulse D, Nelson J, Boothe H. Mechanical evaluation of two canine iliac fracture fixation systems. *Vet Surg*. 1988;17(6):321-327.
12. Fitzpatrick N, Lewis D, Cross A. A biomechanical comparison of external skeletal fixation and plating for the stabilization of ilial osteotomies in dogs. *Vet Comp Orthop Traumatol*. 2008;21(4):349-357.
13. Principles of pelvic fracture management. Seminars in veterinary medicine and surgery (small animal) (USA); 1992.
14. Denny H. Pelvic fractures in the dog: a review of 123 cases. *J Small Anim Pract*. 1978;19(1-12):151-166.
15. Robins G, Dingwall J, Sumner-Smith G. The plating of pelvic fractures in the dog. *Vet Rec*. 1973;93(21):550-554.
16. Hamilton MH, Evans DA, Langley-Hobbs SJ. Feline ilial fractures: assessment of screw loosening and pelvic canal narrowing after lateral plating. *Vet Surg*. 2009;38(3):326-333. https://doi.org/10.1111/j.1532-950X.2009.00500.x.
17. Johnson AL, Houlton JE, Vannini R. *AO Principles of Fracture Management in the Dog and Cat*. Davos Platz, Switzerland: Georg Thieme Verlag; 2005.
18. Scrimgeour AB, Craig A, Witte PG. Locking T-plate repair of ilial fractures in cats and small dogs. *Vet Comp Orthop Traumatol*. 2017;30(6):453-460. https://doi.org/10.3415/VCOT-17-01-0015.
19. Guthrie JW, Kalff S. Tibial plateau levelling osteotomy locking-compression plates for stabilisation of canine and feline ilial body fractures. *J Small Anim Pract*. 2018;59(4):232-237. https://doi.org/10.1111/jsap.12803.
20. Hutcheson KD, Butler JR, Elder SE. Comparison of double locking plate constructs with single non-locking plate constructs in single cycle to failure in bending and torsion. *Vet Comp Orthop Traumatol*. 2015;28(4):234-239. https://doi.org/10.3415/VCOT-14-09-0149.
21. Whelan MF, McCarthy RJ, Boudrieau RJ, Kraus KH. Increased sacral screw purchase minimizes screw loosening in canine triple pelvic osteotomy. *Vet Surg*. 2004;33(6):609-614.
22. Solano MA, Danielski A, Kovach K, Fitzpatrick N, Farrell M. Locking plate and screw fixation after tibial plateau leveling osteotomy reduces postoperative infection rate in dogs over 50 kg. *Vet Surg*. 2015;44(1):59-64.
23. Chiu Y-C, Huang K-C, Shih C-M, Lee K-T, Chen K-H, Hsu C-E. Comparison of implant failure rates of different plates for

midshaft clavicular fractures based on fracture classifications. *J Orthop Surg Res*. 2019;14(1):220.

24. Barnhart MD, Maritato KC. *Locking Plates in Veterinary Orthopedics*. Hoboken, NJ: John Wiley & Sons; 2018.
25. Case JB, Dean C, Wilson DM, Knudsen JM, James SP, Palmer RH. Comparison of the mechanical behaviors of locked and nonlocked plate/screw fixation applied to experimentally induced rotational osteotomies in canine ilia. *Vet Surg*. 2012;41(1):103-113.
26. Kenzig AR, Butler JR, Priddy LB, Lacy KR, Elder SH. A biomechanical comparison of conventional dynamic compression plates and string-of-pearls locking plates using cantilever bending in a canine Ilial fracture model. *BMC Vet Res*. 2017;13(1):222. https://doi.org/10.1186/s12917-017-1139-8.
27. Rose SA, Bruecker KA, Petersen SW, Uddin N. Use of locking plate and screws for triple pelvic osteotomy. *Vet Surg*. 2012;41(1):114-120.
28. Messmer M, Montavon P. Pelvic fractures in the dog and cat: a classification system and review of 556 cases. *Vet Comp Orthop Traumatol*. 2004;17(4):167-183.
29. Johnson KA. *Piermattei's Atlas of Surgical Approaches to the Bones and Joints of the Dog and Cat*. St. Louis, Missouri: Elsevier Health Sciences; 2013.
30. Schmierer PA, Kircher PR, Hartnack S, Knell SC. Screw loosening and pelvic canal narrowing after lateral plating of feline ilial fractures with locking and nonlocking plates. *Vet Surg*. 2015;44(7):900-904. https://doi.org/10.1111/vsu.12367.
31. Schmierer PA, Smolders LA, Zderic I, Gueorguiev B, Pozzi A, Knell SC. Biomechanical properties of plate constructs for feline ilial fracture gap stabilization. *Vet Surg*. 2019;48(1):88-95.
32. Averill S, Johnson A, Schaeffer D. Risk factors associated with development of pelvic canal stenosis secondary to sacroiliac separation: 84 cases (1985-1995). *J Am Vet Med Assoc*. 1997;211(1):75-78.

How to cite this article: Petrovsky B, Knuth T, Aponte-Colón C, et al. Short-term outcomes of 59 dogs treated for ilial body fractures with locking or non-locking plates. *Veterinary Surgery*. 2021;1–11. https://doi.org/10.1111/vsu.13656